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TECHNICAL REPORT

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AN UNPOLARISED ELECTRO-OPTICALLY Q-SWITCHED LASER

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S U M M A R Y

A novel laser design is given that uses a special polarising device to generate unpolarised Q-switched laser energy with a conventional electro-optic Pockels cell. The special polarising device, which replaces the linear polariser normally used in conventional Q-switched resonators, allows solid state lasers to operate efficiently at high repetition rates. Other features of the design include the elimination of the beam non-uniformities that normally occur at high repetition rates, the elimination of the need to bias the Pockels cell and the ability to produce, by a simple mirror realignment, a plane polarised output with high efficiency.

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1.   INTRODUCTION

Conventional electro-optically Q-switched Nd:YAG lasers give less output when thermal birefringence is induced in the laser rod compared to the output produced in the absence of induced birefringence(ref.1).   The explanation for this is that the linear polarising element such lasers contain reject any radiation not plane polarised in the pass plane of the polariser, hence the depolarisation that occurs due to induced birefringence leads to lost energy and poor efficiency.   A further handicap in operating conventional lasers in the presence of thermal birefringence is that the losses vary considerably across the aperture of the laser rod, hence the output beam is non-uniform. The localised regions of high energy density that occur in such beams, called hot spots, are likely to damage laser components at high output power levels. These dual problems of poor efficiency and beam non-uniformity have been fundamental limitations in the development of high repetition rate, Q-switched Nd:YAG lasers.

Techniques exist for maintaining efficiency when birefringence is present but these have some deficiencies. For example the method of Scott and De Wit(ref.2) employs two separate laser rod/flashlamp assemblies and is quite complex.   The polarisation coupled crossed-Porro laser(ref.3) is simpler but the output coupling available at high repetition rates is restricted to near 50% which may not be suitable for lasers generating very high or very low peak powers.   Further, at high input power levels the polarisation coupled laser suffers from hot spots that may be difficult to overcome.   The method of Rankin et al(ref.4) employs a large block of calcite and a large aperture Pockels cell to achieve efficient operation at high repetition rates. Further their output consists of two separate, orthogonally polarised beams that are difficult to manipulate.   One guaranteed method of eliminating all the effects of birefringence is to generate an unpolarised beam.   Electro-optic devices able to switch unpolarised radiation have been fabricated(ref.5,6) but these are not readily available.

In this note a laser design containing a special polarising device is reported that allows the generation of unpolarised Q-switched radiation using commonly available electro-optic Pockels cells.   The method not only gives all the anticipated improvements arising due to the generation of unpolarised radiation, that is, high efficiency at high repetition rates together with the absence of hot spots, but also gives a significant improvement in laser efficiency at low repetition rates due to the very low insertion loss of the polarising device.

2.   LASER GEOMETRY

A schematic diagram of the laser is shown in figure 1.   It operates on a somewhat different principle to that commonly used.   In this laser the polariser doesn't reject any energy and allows the Q-switching action to occur irrespective of the polarisation state of radiation incident on the polariser. The principle of operation of the laser is shown in figure 2.   Radiation, after passing through the birefringent prism is split up into two orthogonally polarised components, the extraordinary (E) and the ordinary (O) rays, that propagate in two slightly different directions.   If these two rays are reflected by M_2 back through the prism a further separation of the two rays will occur.   Provided this separation is of the order of 1^0 the losses in the cavity will be very high and laser action will be suppressed.   However, if a quarter wave voltage is suddenly applied to the Pockels cell the E and O rays returning to the prism from M_2 will be interchanged.   When this happens the walk off occurring in the first pass will be cancelled by an equal and opposite walk-off during the return pass, hence the beam returning to the laser rod will be parallel to the rod axis and losses will be low, allowing a

Q-switched pulse to develop. The output, which is obtained by placing a partially transmitting mirror at M_1, is unpolarised because the switching action is independent of the polarisation state of radiation incident on the prism. An advantage of the design is that in the hold-off condition there is no bias applied to the Pockels cell, hence any possible problems due to electrical leakage or non-uniformity in phase shift across the aperture of the cell are avoided.

Components used in the laser are quite standard with the exception of the birefringent prism. This item is made from calcite and is designed to produce an angular walk-off of 1^0 and to produce a cross-over 60 mm from the prism. This is achieved with a 10mm long calcite prism cut so that the optic axis is inclined at 48° to the entry face. The exit face is inclined at an angle of 6.25° to the entry face and a simple glass prism is used to remove the 3° displacement caused by the calcite prism so that in-line operation occurs. An angular walk-off of 1° is chosen to ensure sufficiently high losses in the Q-spoiled state so that breakthrough is prevented. This angular deviation is not expected to upset the operation of the Pockels cell. A cross-over is used because it allows the rays returning to the rod to completely fill the rod provided, of course, that a quarter wave voltage is applied to the Pockels cell. If the mirror is not placed at the cross-over some restriction in the useful aperture of the rod will result with a corresponding reduction in efficiency. A cross-over to prism spacing of 60 mm was chosen because it was felt most Pockels cell would fit in this space.

Besides allowing the generation of unpolarised radiation using commonly available Pockels cells the design has other useful features. One is that the simplicity of the design of the birefringent prism allows the use of anti-reflection coatings on all surfaces through which radiation must pass, resulting in an insertion loss of about 1/2% per pass compared to as much as 6% loss per pass from a Glan prism, the type of polariser commonly used in conventional Q-switched lasers. Another feature of the design is that it is possible to produce an output that is plane polarised. Further, the output polarisation can be selected between two orthogonal states. In this mode of operation, shown in figure 3, the alignment of mirror M_2 is adjusted to reflect back along the rod axis either the E or O ray. In this case Q-switching is achieved by rapidly removing the quarter wave voltage applied to the Pockels cell. If the laser is operated in this manner it duplicates the characteristics of conventional lasers with, of course, the added benefit of more efficient operation due to lower insertion losses.

3. EXPERIMENTAL

Results obtained with the laser are shown in figures 4 and 5. Also shown are results obtained using the best available linear polariser, a MacNeille type of thin film polariser(ref.7) which was known to have an insertion loss of less than 1.4% per pass. The laser resonator consisted of a short (200mm) conventional Q-switched type with a 100% reflecting mirror at one end and an etalon reflector at the output end of the resonator with an effective reflectivity of about 10%. A Lasermetrics type 1057 KD*P Pockels cell was used for Q-switching and the 75mm x 3mm diameter Nd:YAG rod was placed in an elliptical, close-coupled, pump cavity coated with gold.

The dependence of un-Q-switched output on repetition rate is shown in figure 4. The un-Q-switched output was chosen for comparing the performance of the polarisers because it eliminated the need to re-tune the lasers at each repetition rate, as was necessary when Q-switching. This allowed more reliable data on the relative losses in the resonators to be obtained. The results clearly reveal that the output from the laser employing the special

polariser shows no significant fall-off whereas the output from the laser using a thin film linear polariser shows a 40% fall-off at 250 Hz. It is anticipated that the output per pulse will remain constant up to the point of laser rod fracture (approximately 2000 Hz) provided the other compenents in the resonator, especially the Pockels cell, can handle the power levels required. Limitations set by the power supply and flashlamp prevented investigations at repetition rates above 250 Hz. Besides the improvement in performance at high repetition rates there is also an improvement of about 6% in the output at low repetition rates. This is not related to losses due to thermally induced birefringence in the laser rod but results from the lower insertion loss of the special polariser.

The dependence of Q-switched output on input to the flashlamp at 168 Hz is shown in figure 5 for the special block polariser and for the MacNeille type of polariser. The lasers were tuned for maximum peak power and the laser efficiency at these high repetition rates is almost 50% higher using the block polariser compared to that using the MacNeille type of polariser. These results demonstrate that the 1° angular walk-off of the rays passing through the Pockels cell did not upset its operation.

4. CONCLUSION

An unpolarised Q-switched laser has been developed and shown to be more efficient than a conventional Q-switched laser. Results obtained suggest that Nd:YAG lasers generating unpolarised energy can be efficiently operated up to at least 250 Hz and indications are that efficient operation will occur well above this level, perhaps to levels limited only by the strength of the laser rod. Further, non-uniformities in the output beam that normally occur at high repetition rates are not present in the beam from an unpolarised Q-switched laser.

A simple polarising device has been designed that replaces the linear polariser used in conventional lasers and allows conversion to unpolarised operation. The device can be readily manufactured from calcite or other highly birefringent material and possesses a low insertion loss, an attribute that allows efficient operation at all repetition rates.

The final feature of the design is that the laser allows a choice of plane polarised or unpolarised outputs depending on the alignment of the mirror at the Pockels cell end of the resonator. In the polarised configuration the characteristics of conventional Q-switched lasers are duplicated but with somewhat higher efficiency.

These attributes make the design unique and ideally suited to the operation of high repetition rate Nd:YAG lasers.

5. ACKNOWLEDGEMENTS

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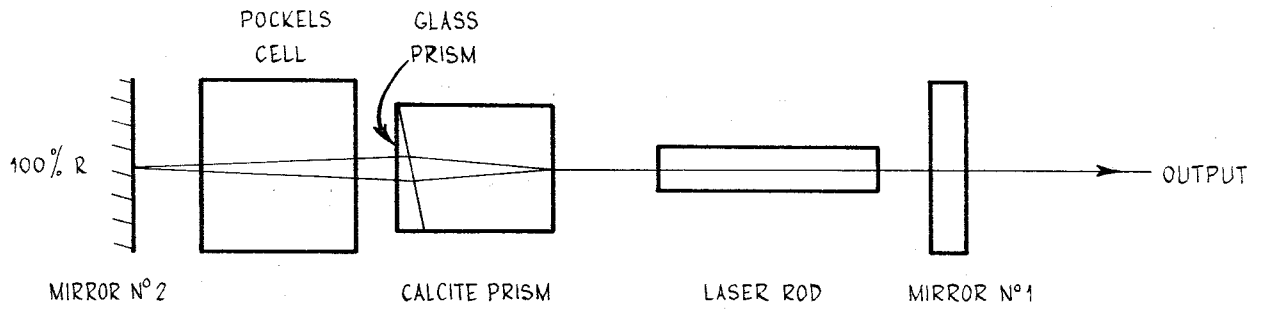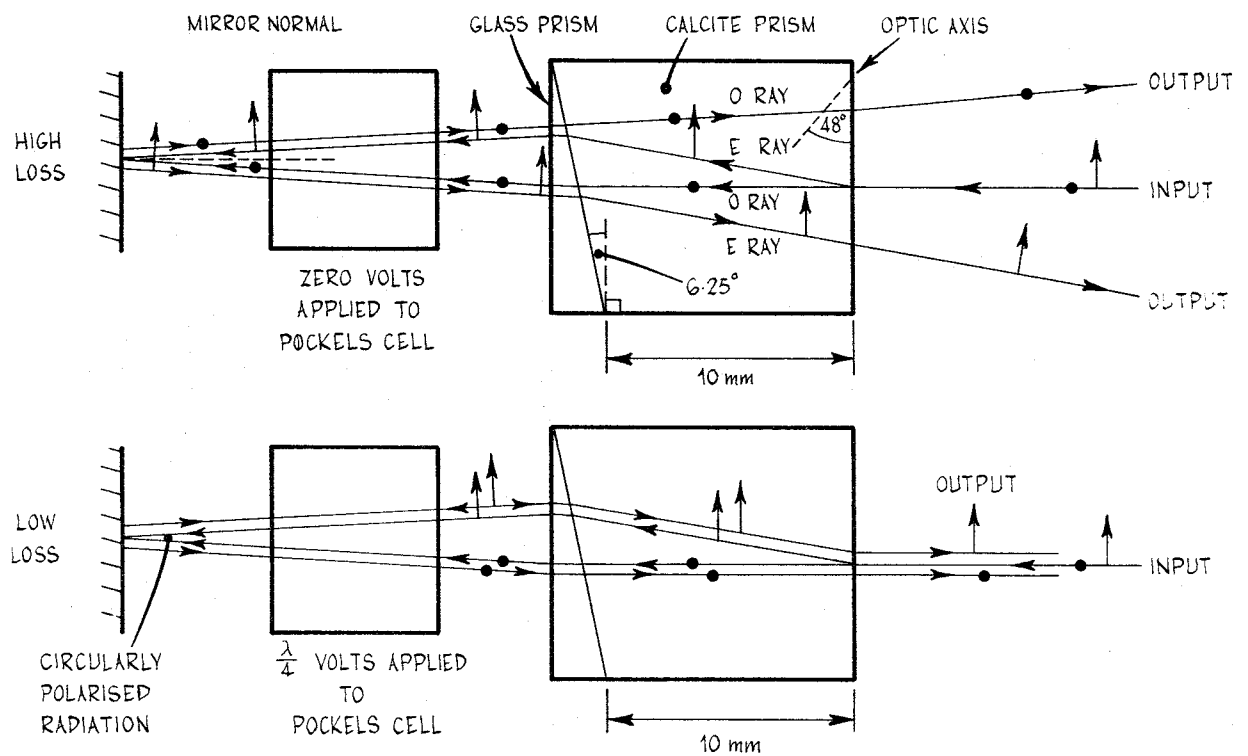| No.	Author	Title
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POCKELS
CELL

GLASS
PRISM

100% R

OUTPUT

MIRROR N°2   CALCITE PRISM   LASER ROD   MIRROR N°1

Figure 1.   Laser geometry

MIRROR NORMAL   GLASS PRISM   CALCITE PRISM   OPTIC AXIS

HIGH
LOSS

O RAY
E RAY
O RAY
E RAY

48°

6·25°

OUTPUT

INPUT

OUTPUT

ZERO VOLTS
APPLIED TO
POCKELS CELL

10 mm

LOW
LOSS

OUTPUT

INPUT

CIRCULARLY
POLARISED
RADIATION

$\frac{\lambda}{4}$ VOLTS APPLIED
TO
POCKELS CELL

10 mm

Figure 2.   Principle of operation

MIRROR NORMAL FOR PRODUCING
VERTICALLY POLARISED OUTPUT

E RAY

O RAY

MIRROR NORMAL FOR
PRODUCING UNPOLARISED
OUTPUT

MIRROR NORMAL FOR
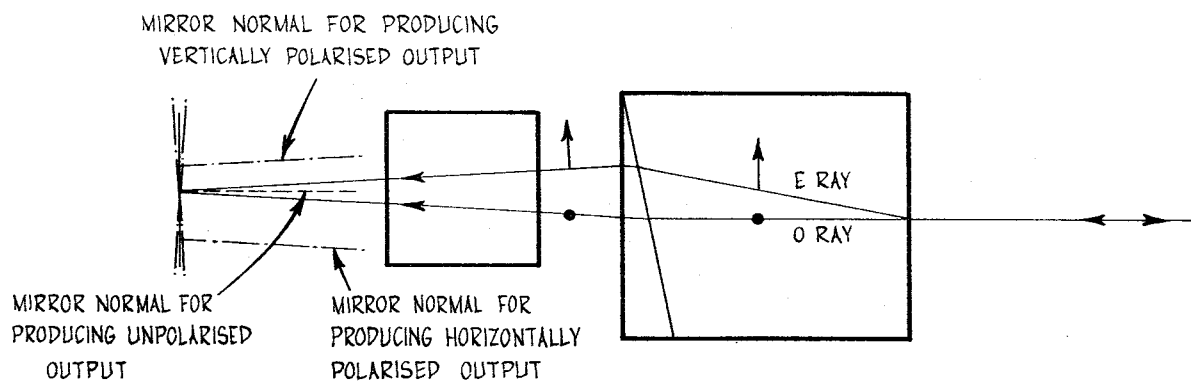PRODUCING HORIZONTALLY
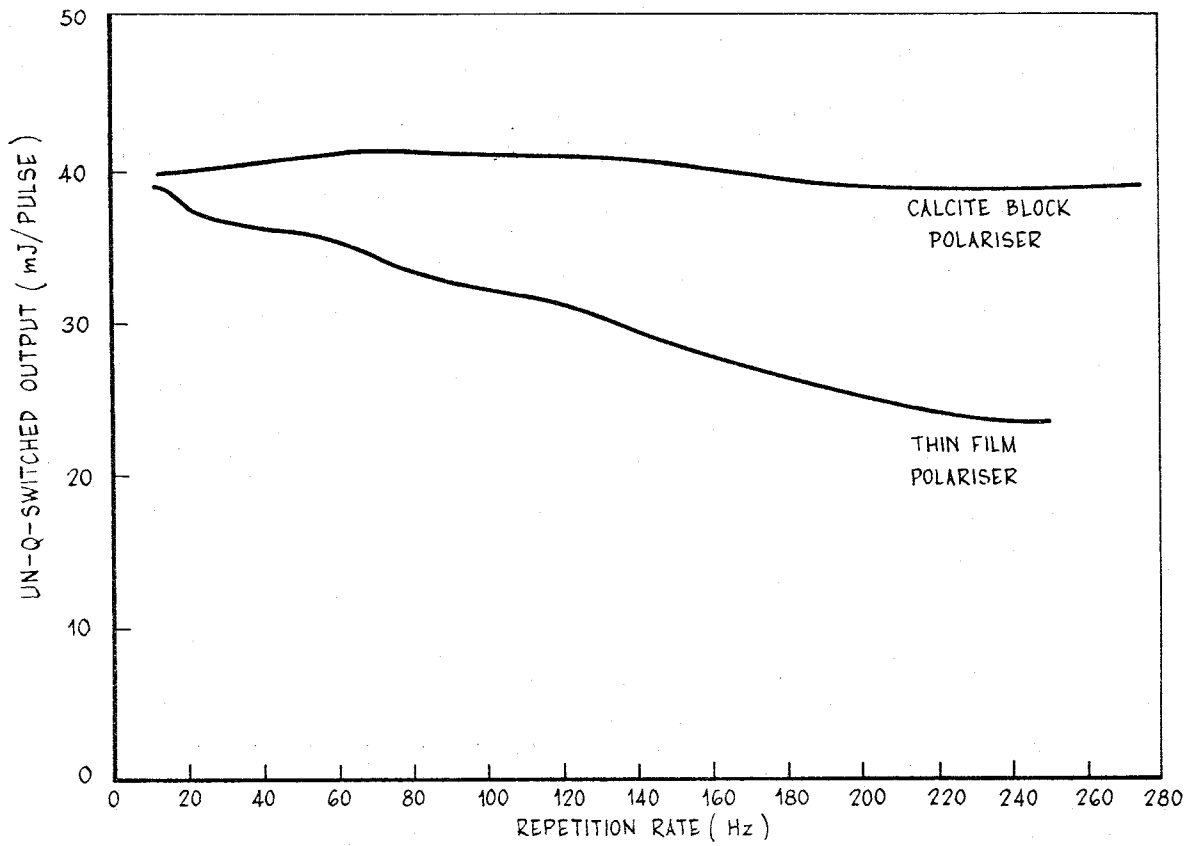POLARISED OUTPUT

Figure 3.   Method of producing plane polarised output

Figure 4. Un-Q-switched output v. repetition rate
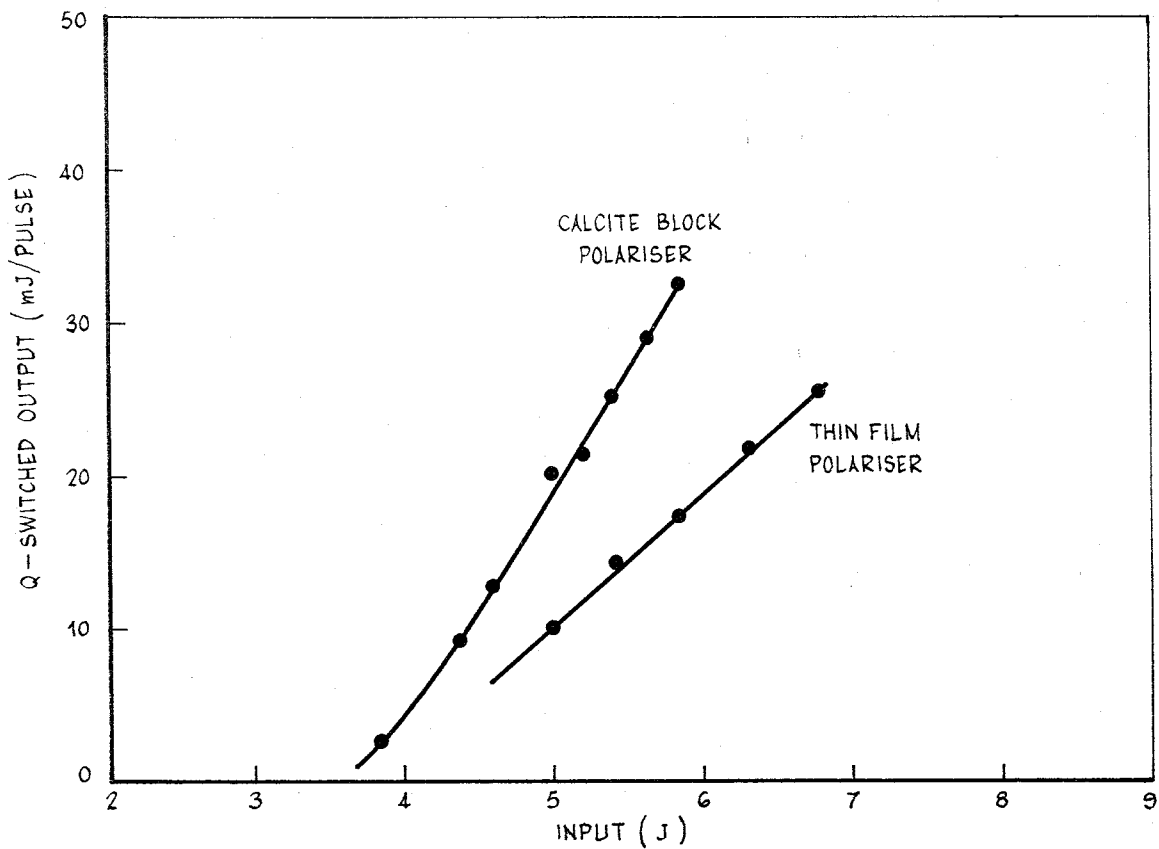
Figure 5. Q-switched output v. input at 168 Hz

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